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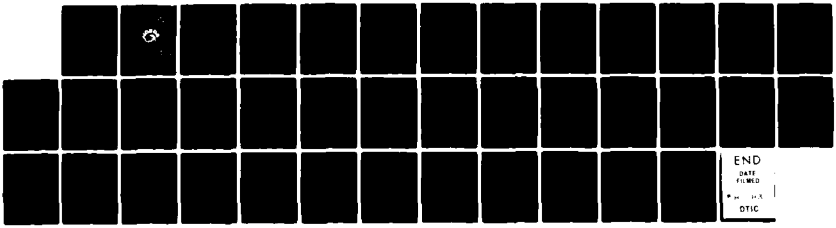

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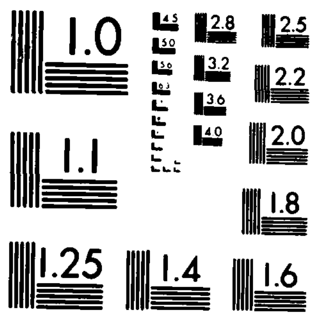

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NORDA Technical Note 182

Naval Ocean Research
and Development Activity
NSTL Station, Mississippi 39529

An Evaluation of Fleet Mission Program Library: Program V10011/B (Bathythermograph→Sound Velocity Profile)

NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY
NORDA
1976

Approved for Public Release
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G.A. Kerr

Ocean Science and Technology Laboratory
Numerical Modeling Division

January 1983

ABSTRACT

A Hewlett Packard 67 (or 97) calculator program used to convert a bathythermograph trace to a sound speed profile was evaluated. The program was found to use a truncated form of Leroy's equation, adequate over the shallow depths (<2000 meters) considered. However, use of a constant oceanic-wide salinity value was found to give erroneous estimates of the layer depth and the depth of the deep sound channel axis in ocean areas where moderately large vertical salinity gradients are encountered. This result led to the recommendation that the program be rewritten to allow the use of a salinity profile representative of the area being sampled.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Richard Lauer, Naval Ocean Research and Development Activity (NORDA), Code 323, for his support and most helpful suggestions during the preparation of this report. The author is grateful to Ms. Charlene Parker, NORDA Code 323, for her help during the preparation of the typed manuscript.

This project was funded by the Tactical Anti-Submarine Warfare Environmental Acoustic Support Project (PE63785N), Mr. Edward Chaika, program manager.

INTRODUCTION

The following is an evaluation of Fleet Mission Program Library program V10011/B. This program, designed for utilization on Hewlett Packard 67 or 97 hand-held calculators, produces sound speeds from bathythermograph (BT) depth-temperature or SSQ-36 sonobuoy time-frequency measurements. The program utilizes a truncated form of Leroy's (1968) equation and considers salinity a constant value. The evaluation concerns itself with four questions:

- Is Leroy's equation accurately reproduced by the program?
- Does the program give identical results for all sets of input units?
- What is the severity of the sound speed errors produced by the assumption of a constant salinity?
- Can better results be obtained through the use of other sound speed equations?

In the following evaluation, sound speed errors ≤ 0.6 m/sec were considered insignificant since the magnitude of the error introduced through BT inaccuracies are of this magnitude (Pichett, 1972). Also, reference sound speeds derived from Wilson's (1960) equation were expected to be within 0.6 m/sec of the actual sound speed 95 percent of the time.

Significance of terms omitted from Leroy's original equation set

Leroy's (1968) second equation, approximated by the calculator program, is given by Eq. 1 below.

$$V^1 = Vo^1 + Va^1 + Vb^1 + Vc^1 + Vd^1 \qquad (1)$$

where

$$Vo^1 = 1493.0 + 3\,(T-10) - 6 \times 10^{-3}(T-10)^2$$
$$- 4 \times 10^{-2}\,(T-18)^2 + 1.2(S-35) - 10^{-2}(T-18)(S-35) + Z/61,$$

$$Va^1 = +10^{-1}\,\beta^2 + 2 \times 10^{-4}\,\beta^2(T-18)^2$$
$$+ 10^{-1}\,\beta\,\Psi/90,$$

$$Vb^1 = +\,2.6 \times 10^{-4}T(T-5)(T-25),$$

$$Vc^1 = -10^{-3}\ \beta^2(\beta-4)(\beta-8),$$

$$Vd^1 = 1.5 \times 10^{-3}\ (S-35)^2\ (1-\beta)$$
$$+ 3 \times 10^{-6}T^2(T-30)(S-35)$$

and where

V^1, Vo^1, Va^1, Vb^1, Vc^1, and Vd^1 are sound speeds in m/sec,

T is the temperature in degrees centigrade (°C),

S is the salinity in parts per thousand (ppt),

Z is the depth in meters (m),

β is the depth in kilometers and (km),

Ψ is the latitude in degrees.

Because of limited program space, approximately 20 program steps are left unused (Dr. Tom Richardson (CPWL), personal communication) only the Vo^1 and Vb^1 terms of Eq. (1) were retained. Using estimated ranges of 32 ppt to 39.5 ppt for salinity, 2°C to 28°C for temperature, 0 km to 2 km for depth, and 0° to 85° for latitude, estimates of the maximum sound speed differences produced by the omission of the Va^1, Vc^1, and Vd^1 terms were found. The absolute values of these resulting omission errors are given below:

$Va^1 \approx 0.7$ m/sec,

$Vc^1 \approx 0.1$ m/sec,

$Vd^1 \approx 0.3$ m/sec.

Considering the above magnitudes and the dependencies within the terms, it must be concluded that only the omission of Va^1 term may be of significance. The Va^1 error would become large at high latitudes, at depth, and in cold water, conditions which are easily met. Since this term is not included in the calculator program, a profile generated from the modified algorithm would, in general, taper away, or indicate increasingly lower sound speeds with depth, when compared to a profile generated using the complete equation. Figure 1 illustrates this phenomenon occurring below the deep sound channel axis.

Using average oceanic temperatures (Defant, 1961) the magnitude of the Va^1 omission error varies from nearly 0.1 m/sec at 600 m to approximately 0.7 m/sec at 2000 m. Such small errors and resulting gradient errors (3×10^{-4} m/sec/m at 600 m and 6×10^{-4} m/sec/m at 2000) may be considered inconsequential when the depths involved in the calculation are not greater than those normally achieved by an expendable BT ($\approx$2000 m). As Figure 1 illustrates, the magnitude of the error introduced by the omission of the Va^1 term increases significantly at depths greater than 2000 m. At 4000 m, in this

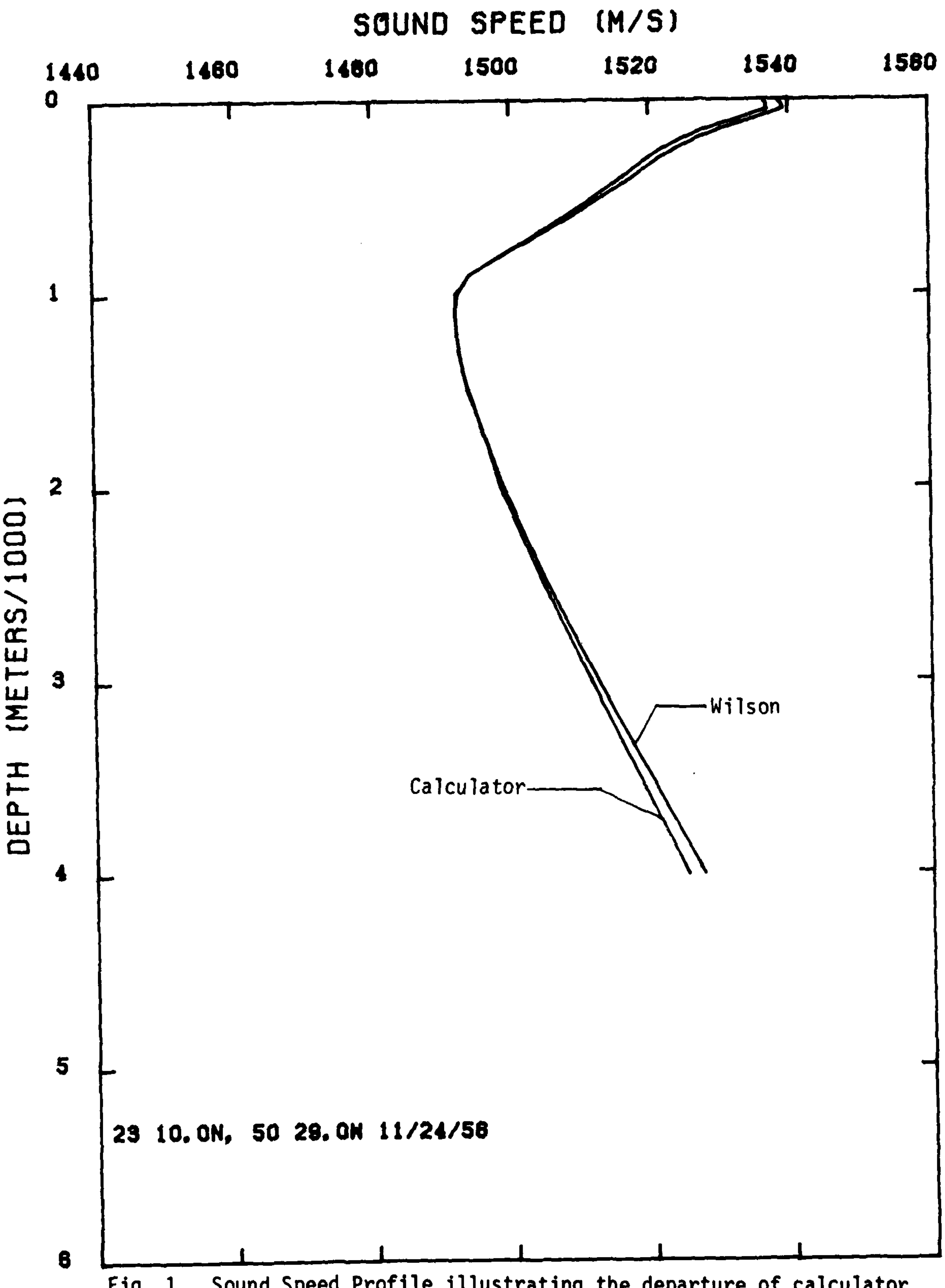

Fig. 1. Sound Speed Profile illustrating the departure of calculator derived sound speeds from Wilson's equation sound speeds at *depth*.

example, the magnitude of the sound speed error due to neglecting the Va^1 term is approximately 2.2 m/sec.

In summary, at depths <2000 m, omission of the Va^1, Vd^1 and Vc^1 terms from Leroy's equation will not significantly alter those sound speeds found through the use of the complete equation. However, significant sound speed errors can occur when depths are in excess of 2000 m.

Comparison between calculator and Leroy's Vo^1 and Vb^1 terms

The purpose of this section is to determine whether significant sound speed variations result from differences between the calculator program's version and the originally published Vo^1 and Vb^1 terms of Leroy's equation. To accomplish this, both forms were manipulated to obtain cubic equations in temperature. In the process, the calculator version was converted to the metric form. Salinity was considered to be equal to 35 ppt, thereby removing the sound speed dependence on salinity.

Table 1 lists the coefficients of temperature raised to powers from zero to three for both equations, in addition to the coefficient differences. At 25°C, the coefficient discrepancies result in a sound speed difference of approximately 0.3 m/sec. If the Mediterranean Sea program option (salinity = 38.6 ppt) is used, the T^0 and T^1 coefficient differences become -0.0032 and -0.0051, respectively. The Mediterranean coefficient changes do not significantly alter the 0.3 m/sec sound speed difference indicated above, since the major portion of the sound speed difference is produced by the T^2 term.

It can be concluded, therefore, that the small sound speed variations brought about by the small discrepancies in the equation coefficients cannot be considered significant, and that the calculator program adequately represents the Vo^1 and Vb^1 terms of Leroy's original equation.

Table 1. Comparison of the coefficients of calculator and Leroy's original Vo^1 and Vb^1 terms.

Power of Temperature	Coefficient: From Leroy's original equation (1)	Coefficient: Calculator equation (2)	Difference (1) - (2)
0	1449.44	1449.51	-0.07
1	4.5925	4.5946	-0.002
2	-5.38×10^{-2}	-5.38×10^{-2}	0
3	2.6×10^{-4}	2.6×10^{-4}	0

Comparison between results obtained using various data entry options

A test set of data, Table 2, was constructed using the unit conversion equations given in the program documentation to test the results of all program data entry options. The program gave the same results, depths in feet, and sound speeds in feet per second for all sets of entry units under both normal and Mediterranean Sea options.

Table 2. Program Test Entry Data Sets and Program Results

Depth		Entry Temperature		Time		Freq.	Result Sound Speed ft/sec	
Meters	Entry & Result Feet	^oC	^oF	Sec	Hr/Min/Sec	Hz	Normal	Med
0	0	29.54	85.17	0	0	2503.44	5069	5082
10	32	29.51	85.12	6.56	.000656	2502.36	5069	5082
20	65	29.42	84.96	13.12	.001312	2499.12	5069	5082
30	98	29.26	84.67	19.68	.001968	2493.36	5068	5081
50	164	28.86	83.95	32.81	.003281	2478.96	5067	5080
75	246	26.02	78.84	49.21	.004921	2376.72	5047	5061
100	328	24.40	75.92	65.62	.010562	2318.40	5036	5049
125	410	23.49	74.28	82.02	.012202	2285.64	5030	5044
150	492	22.47	72.45	98.42	.013842	2248.92	5023	5037
200	656	20.10	68.18	131.23	.021123	2163.60	5005	5019
250	820	18.84	65.91	164.04	.024404	2118.24	4996	5010
300	984	17.88	64.18	196.85	.031685	2083.68	4990	5004
400	1312	16.63	61.93	262.47	.042247	2038.68	4983	4997
500	1640	14.35	57.83	328.08	.052808	1956.60	4965	4979
600	1968	11.88	53.38	393.70	.063370	1867.68	4943	4958
700	2296	9.44	48.99	459.32	.073932	1779.84	4920	4936
800	2624	8.00	46.40	524.93	.084493	1728.00	4908	4924
900	2952	6.63	43.93	590.55	.095055	1678.68	4896	4912
1000	3280	5.92	42.66	656.17	.105617	1753.12	4893	4908
1100	3608	5.47	41.85	721.78	.120178	1636.92	4892	4908
1200	3937	4.97	40.95	787.40	.130740	1618.92	4891	4906
1300	4265	4.65	40.37	853.02	.141302	1607.40	4892	4907
1400	4593	4.30	39.74	918.64	.151864	1594.80	4892	4908
1500	4921	4.06	39.31	984.25	.162425	1586.16	4895	4910
1750	5741	3.72	38.70	1148.29	.190829	1573.92	4903	4919

Variations in sound speed and sound speed gradients due to the assumption of a constant salinity

From Eq. (1), neglecting the Vd[1] term (used only for low salinity), the variation of sound speed with salinity is approximately 1.3 m/sec/ppt. The form of Leroy's equation used in the calculator program considers salinity a constant. A value of 35 ppt is used in all oceans (Northern Hemisphere Atlantic and Pacific assumed) except in the Mediterranean Sea where a value of 38.6 ppt is utilized. Without inclusion of polar zones, Defant (1961) gives average salinities for the Atlantic and Pacific Oceans of 35.45 ppt and 34.17 ppt, respectively. Von Arx (1967) gives an average salinity of 38.6 ppt for the Mediterranean Sea. According to Defant (1961), then, the average sound speeds calculated for the Pacific Ocean would be nearly 0.6 m/sec too high. Sound speeds calculated for the Atlantic Ocean would be approximately 1.1 m/sec too low. These small differences, which would not change the shape of the sound speed profile, can be considered insignificant in a majority of acoustic applications.

In the Atlantic and Pacific Oceans the salinity can be expected to be between 32 ppt and 37 ppt. In the Mediterranean Sea the salinity range is approximately 35 ppt to 39.5 ppt. The resulting sound speed errors induced by considering salinity a constant 35 ppt in the Atlantic and Pacific Oceans would be between -3.9 m/sec and 2.6 m/sec. In the Mediterranean Sea, the resulting sound speed errors, using a 38.6 ppt constant salinity, would be between -4.7 m/sec and 1.2 m/sec. For ranging applications, errors near the extremes of the above ranges may be important. For transmission loss (propagation loss) applications it is important to know how these errors are distributed over depth or how salinity gradients modify the shape of the sound speed profile.

To investigate the relationship between the salinity gradient and the shape of the sound speed profile, Nansen cast data were obtained in several regions where large salinity variations with depth were expected. In the following examples, calculator sound speeds in ft/sec were derived from Nansen cast temperatures at standard depths. Data from depths in excess of 2000 m were not considered. A unit conversion to meters per second was made and in the process one decimal digit was retained. For comparison purposes, Wilson sound speeds in m/sec were calculated from the Nansen cast temperature and salinity data at standard depths. An additional sound speed profile was constructed from the calculator derived sound speeds through the addition of a salinity sound speed correction applied at each standard depth.

The salinity correction in each area was found by first taking the difference between the mean salinity at each standard depth and the constant salinity value and then multiplying the result by 1.3 m/sec/ppt. The areas from which the mean salinities were derived were from 1° to 4° square, roughly centered on the Nansen cast location. The size of each area was determined by data density.

For a final comparison the Nansen cast temperature profile was plotted to simulate the BT trace which would have been obtained for each example data set. Points were selected from the temperature profile at locations where a temperature gradient change was visually obvious. It is believed that the above procedure must closely approximate that used at sea, and will provide the most

important comparisons between Wilson and calculator derived sound speed profiles in the example areas selected.

Example 1. North Pacific Ocean (Bering Sea) 59°0.0'N, 179°42.0'E, 6/14/62

From Table 3 it is evident that the 2 m/sec to 3 m/sec sound speed differences between the surface and 300 m are due to the salinity differences (≈2 ppt) between the in situ salinity and the calculator's use of a constant 35 ppt salinity. It is evident, from Figure 2, that the sound speed gradients of both profiles are similar. In this example, the salinity gradients were not of sufficient magnitude to cause a change in the deep sound channel axis depth or a significant change in the sound speed gradients. Table 4 and Figure 3 illustrate the improved correlation between sound speeds at all depths as a result of the addition of the salinity correction to the calculator program sound speeds.

Figure 4 illustrates the temperature profile obtained from this first example data set. Temperature gradient changes are evident at depths of 20, 75, 200, and 300 m. Selection of temperatures at these depths in addition to those at the surface and the bottom would provide, through the use of the calculator program, an accurate estimate of the layer depth (zero) and the depth of the deep sound channel axis. However, as Table 4 illustrates the sound speed magnitude at the surface and the deep sound channel axis would be in error by nearly 3 m/sec. If the salinity correction is applied, the magnitude of the above errors is reduced to 0.4 m/sec.

Example 2. Mediterranean Sea, Straits of Gibraltar, 35°57.8'N, 5°27.3'W, 5/24/61

In the Straits of Gibraltar, relatively fresh Atlantic waters occupy the uppermost layers of water while the more saline waters typical of the Mediterranean occupy the lower layers. Table 5 and Figure 5 illustrate the rather large sound speed differences attributable to the difference between the in situ salinity and the assumed constant salinity of 38.6 ppt.

In this particular example, the lowest in situ salinity defines the sound channel axis depth. The calculator program's use of a constant salinity of 38.6 ppt (for the Mediterranean Sea) was incapable of reproducing the sound channel axis depth derived from the use of Wilson's equation. The magnitude of the difference in this example was 75 m. Table 6 and Figure 6 illustrate how the shape of the actual sound speed profile is retained when the salinity sound speed correction is applied to the calculator derived sound speeds.

Figure 7 illustrates the temperature profile resulting from this second example data set. Obvious temperature gradient changes occur at depths of 20, 50, 75, and 125 m. If the temperature at these depths in addition to those at the surface and bottom were used in the calculator program, an accurate estimate of the layer depth would be obtained. The depth of the deep sound channel axis would remain in error by 75 m. In addition, the sound speeds at the surface and at the bottom of the layer would be incorrect. The magnitudes of these errors, given in Table 5, are approximately 2.5 m/sec. If the salinity correction is applied (Table 6) the above sound speed errors are reduced to 0.4 m/sec, and with some knowledge of the area, the correct sound channel axis depth might be selected.

Table 3. Comparison between calculator derived sound speeds and Wilson's derived sound speeds for Example 1.

Depth (m)	Temp (C)	Salinity (PPT)	Salinity -35 (PPT)	Wilson Sound Speed (m/s)	Calculator Sound Speed (m/s)	Wilson-Calc. Sound Speed (m/s)
0	5.00	32.97	- 2.03	1468.3	1471.3	- 3.0
10	4.92	32.97	- 2.03	1468.1	1471.0	- 2.9
20	4.79	32.97	- 2.03	1467.8	1470.7	- 2.9
30	4.23	32.99	- 2.01	1465.6	1468.5	- 2.9
50	3.39	33.01	- 1.99	1462.4	1465.2	- 2.8
75	2.29	33.02	- 1.98	1458.1	1460.9	- 2.8
100	2.28	33.07	- 1.93	1458.5	1461.2	- 2.7
125	2.43	33.12	- 1.88	1459.6	1462.4	- 2.8
150	2.45	33.14	- 1.86	1460.2	1463.0	- 2.8
200	2.58	33.21	- 1.79	1461.6	1464.3	- 2.7
250	3.07	33.36	- 1.64	1464.8	1467.3	- 2.5
300	3.68	33.59	- 1.41	1468.5	1470.7	- 2.2
400	3.81	33.87	- 1.13	1471.1	1472.8	- 1.7
500	3.70	34.04	- .96	1472.5	1474.0	- 1.5
600	3.54	34.12	- .88	1473.6	1474.9	- 1.3
700	3.40	34.18	- .82	1474.8	1475.8	- 1.0
800	3.26	34.24	- .76	1475.9	1477.1	- 1.2
900	3.10	34.29	- .71	1477.0	1478.0	- 1.0
1000	2.95	34.34	- .66	1478.1	1478.9	- .8
1100	2.80	34.38	- .62	1479.2	1480.1	- .9
1200	2.65	34.41	- .59	1480.3	1481.0	- .7

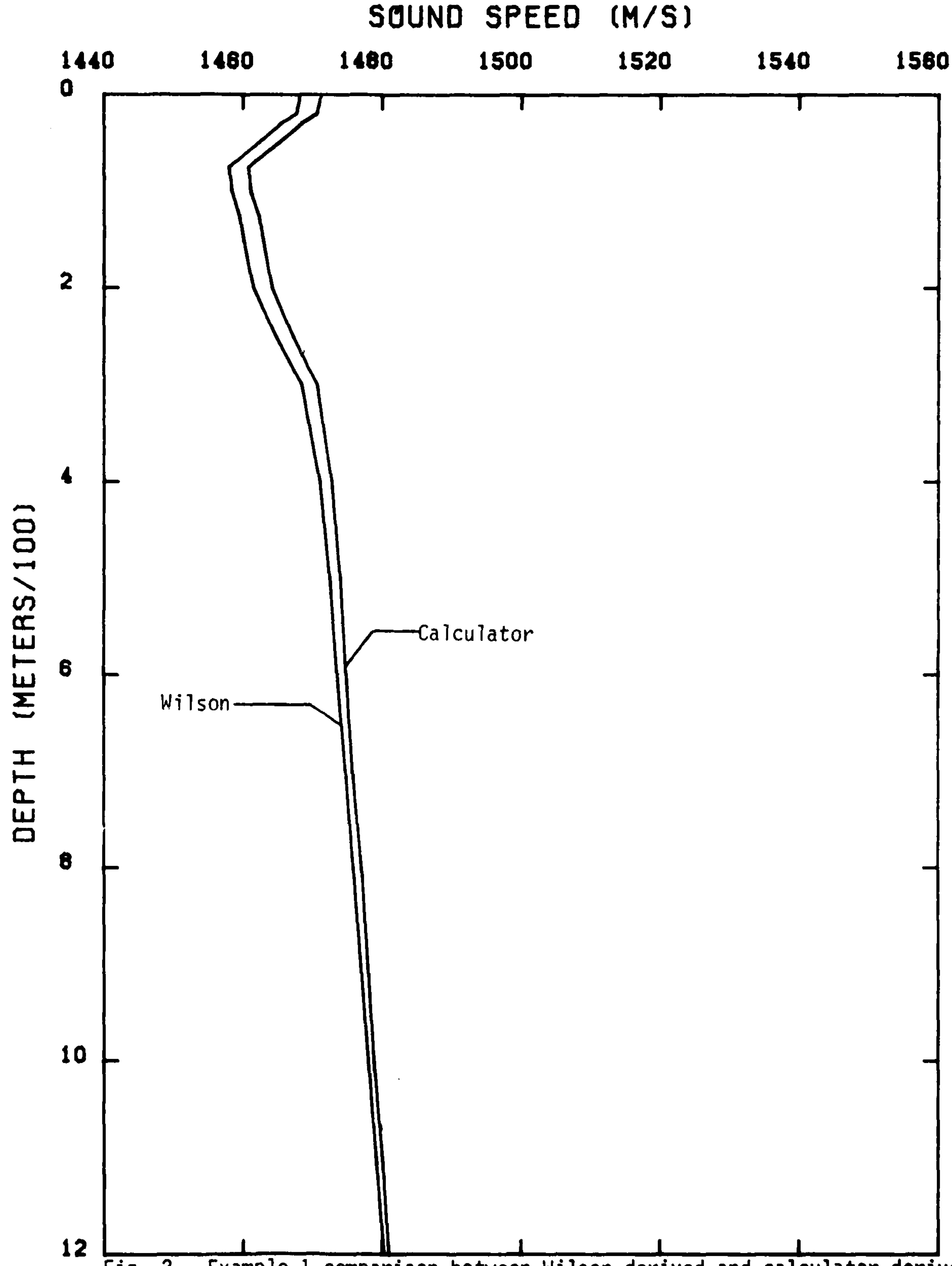

Fig. 2. Example 1 comparison between Wilson derived and calculator derived sound speed profiles.

Table 4. Comparison between salinity corrected calculator derived sound speeds and Wilson's equation derived sound speeds for Example 1

Depth (m)	Mean Salinity (PPT)	Sound Speed Correction @1.3 m/sec/PPT (m/s)	Calculator Corrected Sound Speed (m/s)	Wilson-Corrected Calculator Sound Speed (m/s)
0	32.99	- 2.6	1468.7	- .4
10	32.96	- 2.6	1468.4	- .3
20	32.99	- 2.6	1468.1	- .3
30	33.01	- 2.6	1465.9	- .3
50	33.08	- 2.5	1462.7	- .3
75	33.15	- 2.4	1458.5	- .4
100	33.20	- 2.3	1458.9	- .4
125	33.22	- 2.3	1460.1	- .5
150	33.23	- 2.3	1460.7	- .5
200	33.39	- 2.1	1462.2	- .6
250	33.62	- 1.8	1465.5	- .7
300	33.77	- 1.6	1469.1	- .6
400	33.95	- 1.4	1471.4	- .3
500	34.07	- 1.2	1472.8	- .3
600	34.15	- 1.1	1473.8	- .2
700	34.21	- 1.0	1474.8	0
800	34.27	- .9	1476.2	- .3
900	34.32	- .9	1477.1	- .1
1000	34.37	- .8	1478.1	0
1100	34.42	- .8	1479.3	- .1
1200	34.46	- .7	1480.3	0

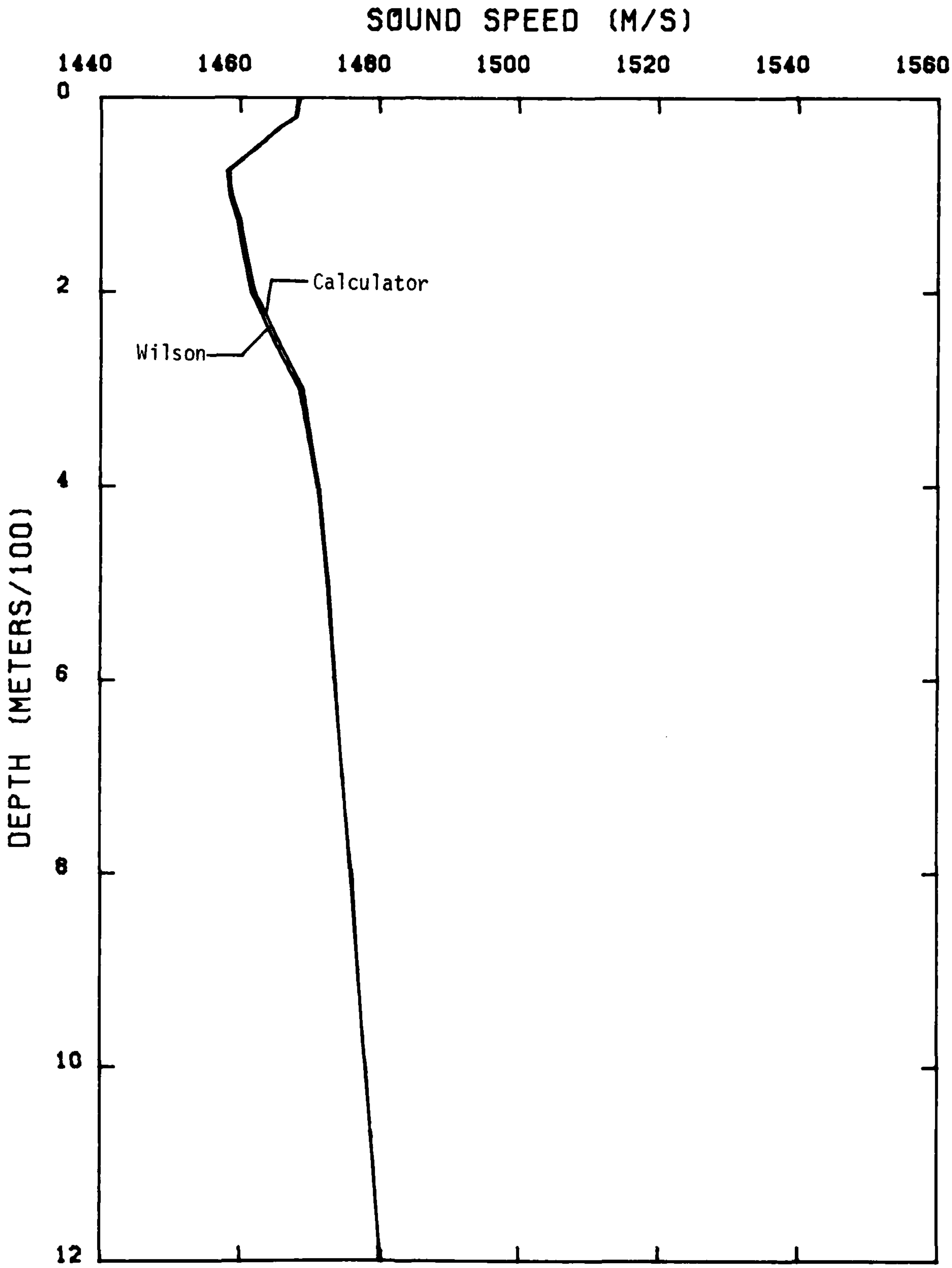

Fig. 3. Example 1 comparison between Wilson derived and the salinity corrected calculator derived sound speed profiles.

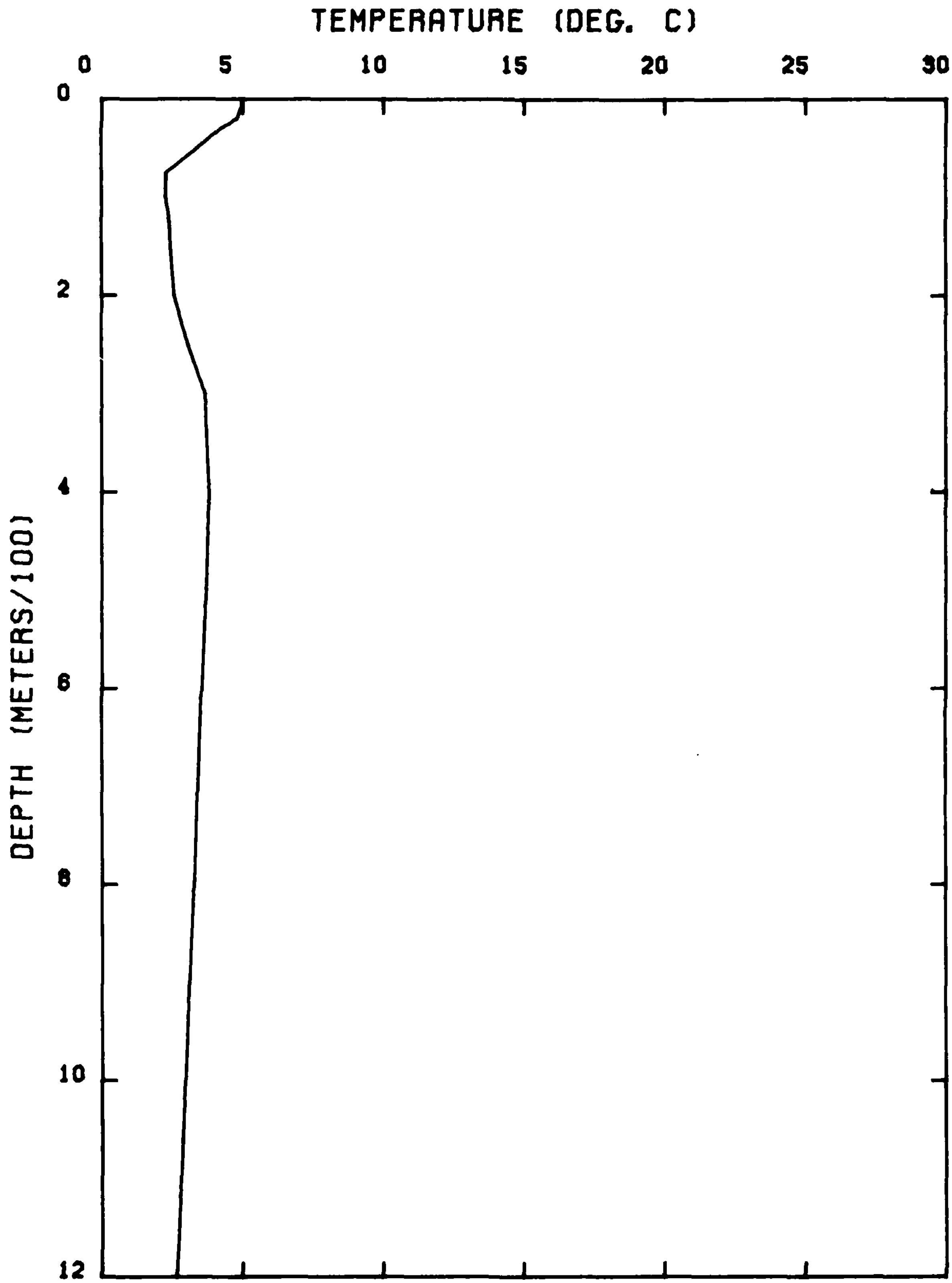

Fig. 4. Example 1 in situ temperature profile.

Table 5. Example 2 comparison between calculator and Wilson derived sound speeds.

Depth (m)	Temp (C)	Salinity (PPT)	Salinity - 38.6 (PPT)	Wilson Sound Speed (m/s)	Calc. Sound Speed (m/s)	Wilson-Calc. Sound Speed (m/s)
0	18.64	36.33	- 2.27	1519.9	1522.5	- 2.6
10	18.66	36.32	- 2.28	1520.1	1522.5	- 2.6
20	18.69	36.28	- 2.32	1520.3	1522.8	- 2.5
30	17.41	36.10	- 2.50	1516.6	1519.4	- 2.8
50	14.06	36.02	- 2.58	1506.5	1509.4	- 2.9
75	13.91	37.11	- 1.49	1507.7	1509.4	- 2.7
100	13.47	37.81	- .79	1507.6	1508.5	- .9
125	13.19	38.07	- .53	1507.4	1507.9	- .5
150	13.12	38.16	- .44	1507.7	1508.2	- .5
200	13.09	38.26	- .34	1508.5	1508.8	- .3
250	13.02	38.35	- .25	1509.3	1509.4	- .1
300	13.02	38.46	- .14	1510.2	1510.3	- .1
400	12.97	38.44	- .16	1511.7	1511.5	.2
500	12.94	38.45	- .15	1513.2	1513.0	.2
600	12.92	38.46	- .14	1514.8	1514.9	- .1
700	12.91	38.45	- .15	1516.4	1516.4	0

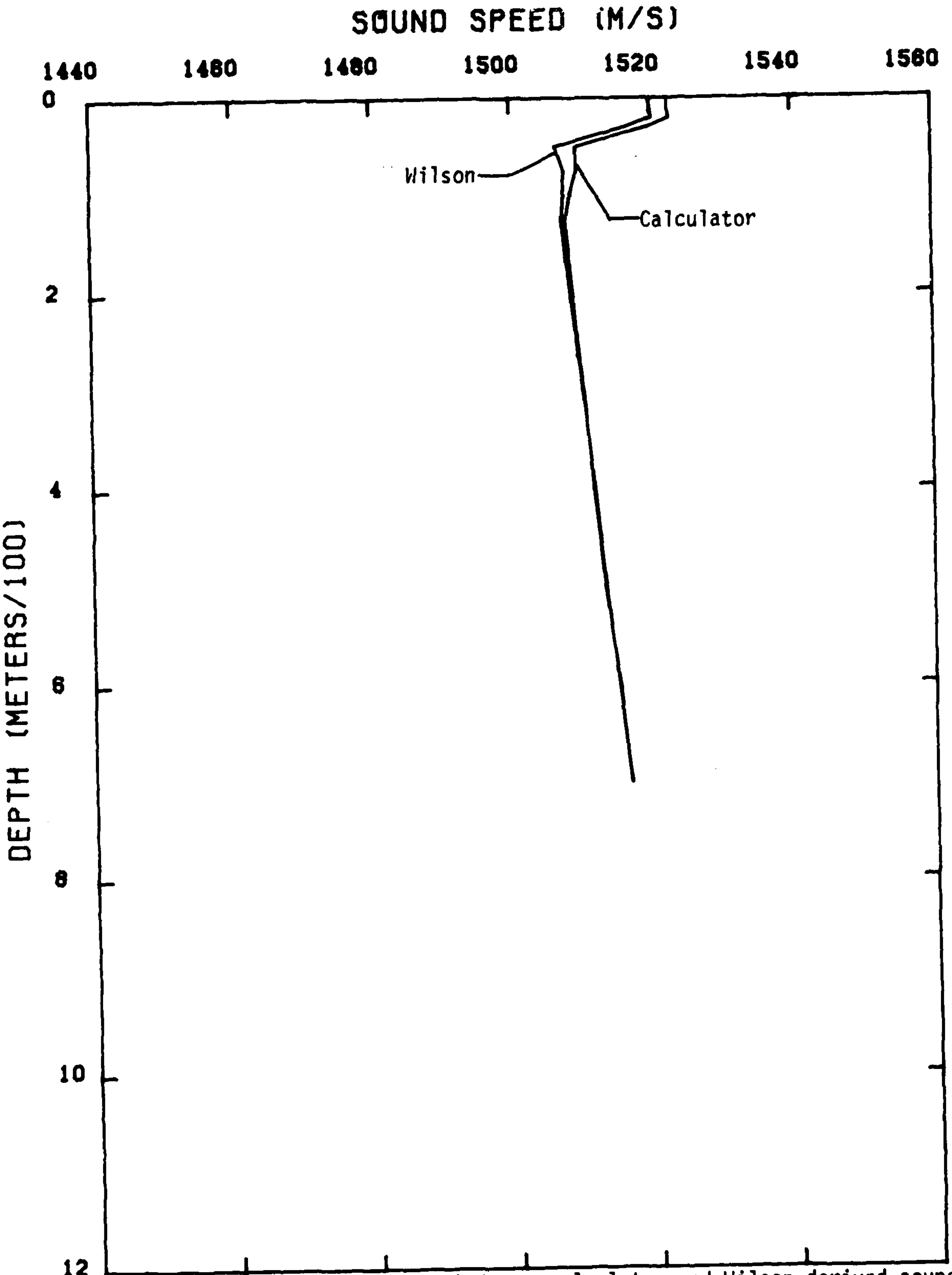

Fig. 5. Example 2 comparison between calculator and Wilson derived sound speed profiles.

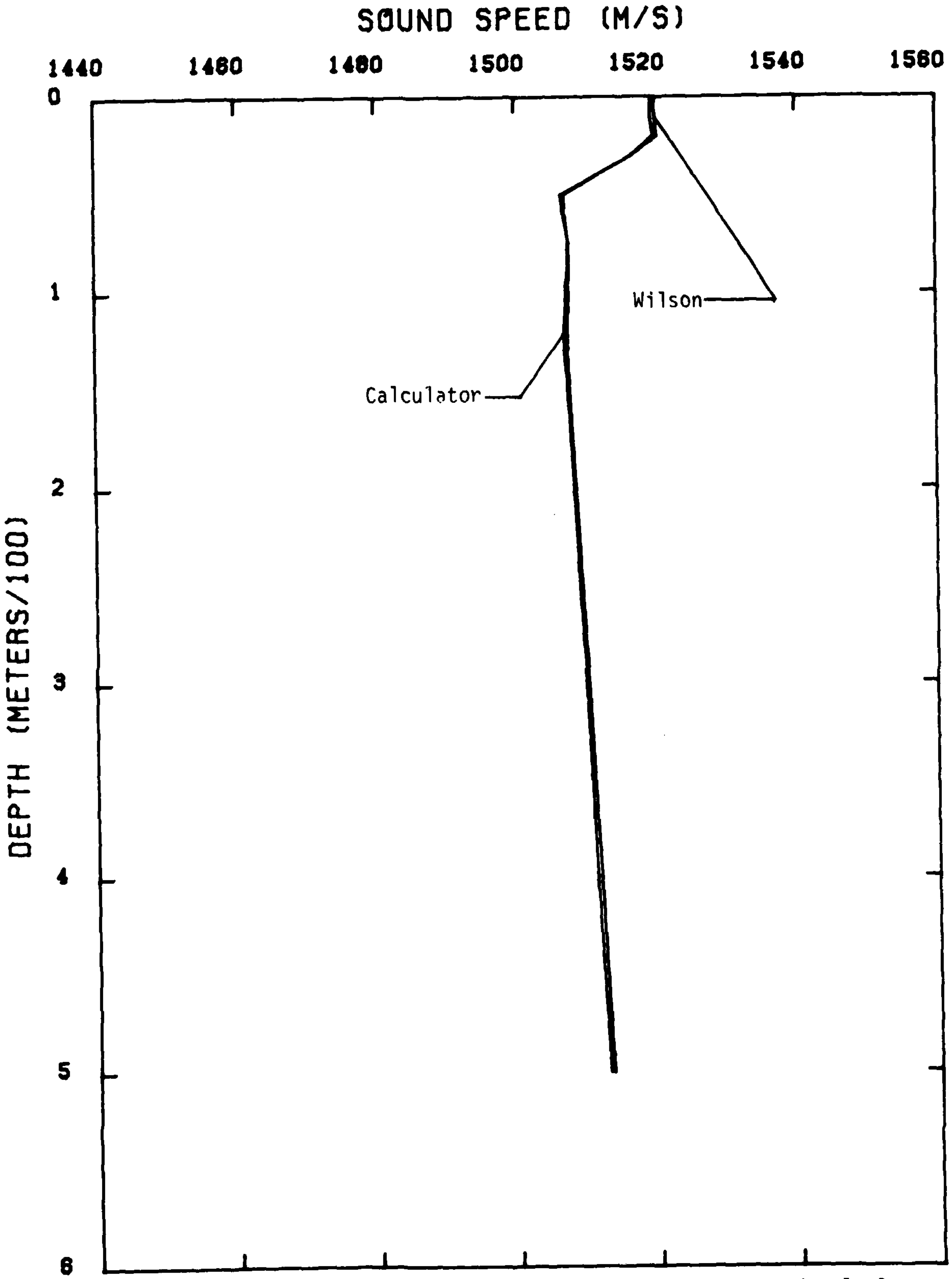

Fig. 6. Example 2 comparison between the salinity corrected calculator and Wilson derived sound speed profiles.

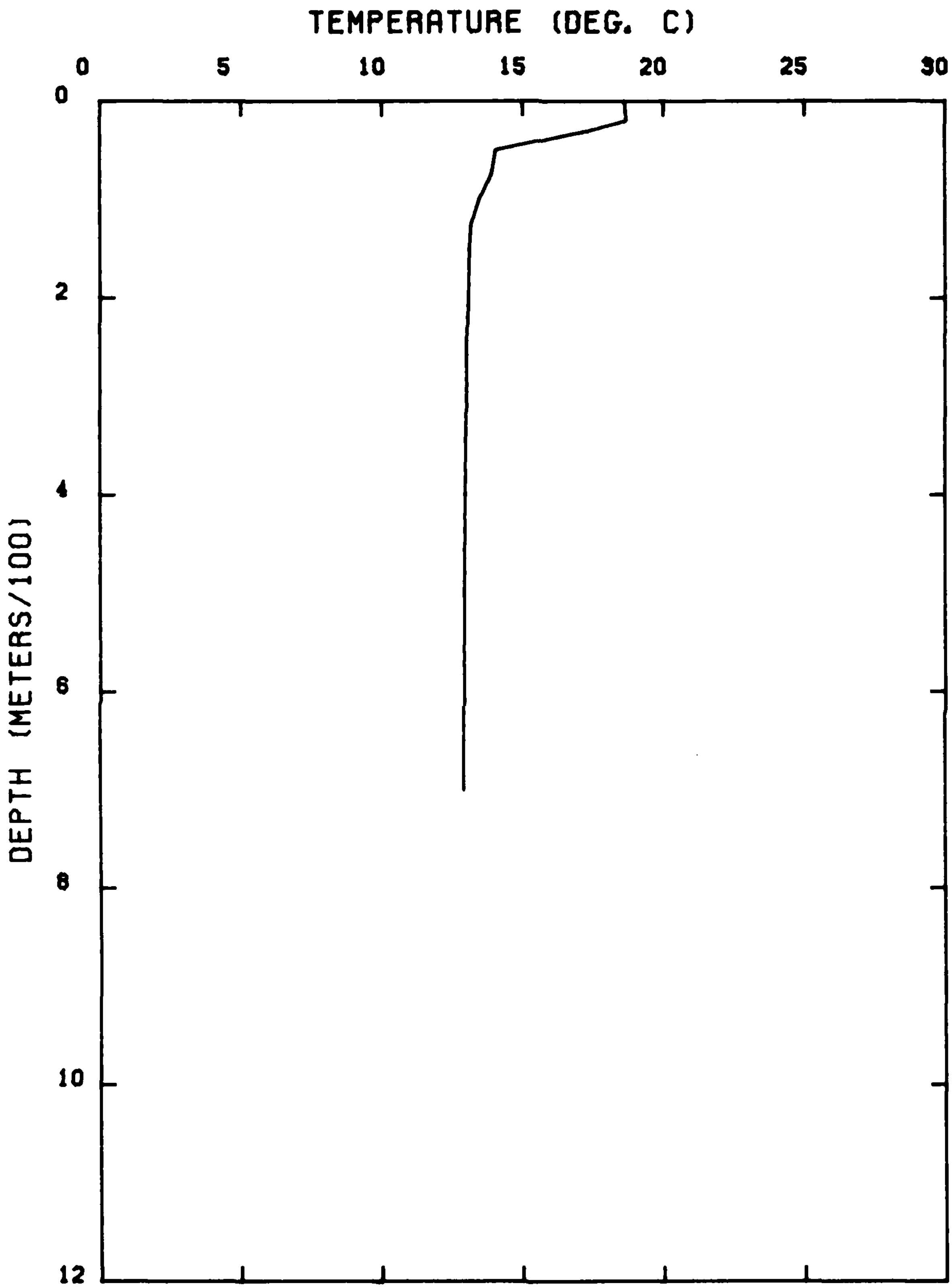

Fig. 7. Example 2 in situ temperature profile.

Table 6. Comparison between the salinity corrected calculator and Wilson derived sound speed for Example 2.

Depth (m)	Mean Salinity (PPT)	Sound Speed Correction 1.3 m/sec/PPT (m/s)	Calculator Corrected Sound Speed (m/s)	Wilson-Corrected Calculator Sound Speed (m/s)
0	36.31	- 3.0	1519.5	. 4
10	36.31	- 3.0	1519.5	. 6
20	36.34	- 2.9	1519.9	. 4
30	36.46	- 2.8	1516.6	0
50	36.77	- 2.4	1507.0	-. 5
75	37.26	- 1.7	1507.7	0
100	37.65	- 1.2	1507.3	. 3
125	37.91	- .9	1507.0	. 4
150	38.06	- .7	1507.5	. 2
200	38.23	- .5	1508.3	. 2
250	38.32	- .4	1509.0	. 3
300	38.36	- .4	1509.9	. 3
400	38.40	- .3	1511.2	. 5
500	38.42	- .2	1512.8	. 4
600	--	--	--	--
700	--	--	--	--

Example 3. Atlantic Ocean, Windward Passage, 20°28.0'N, 73°18.0'W, 9/22/63

Table 7 illustrates that in the Windward Passage there exists an increase of salinity with depth from the surface to a depth of 150 m. The salinity gradient is especially large (0.025 ppt/m) between 10 m and 50 m. Over this same depth interval, the temperature decreases by only 0.65°C. Due to the large salinity gradient, not accounted for by the calculator program, the layer depth, Figure 8, is underestimated by 30 m.

From Urick (1975) an estimate of the *maximum wavelength in feet*, trapped in a mixed-layer duct H feet thick, can be obtained from Equation 2.

$$\lambda_{max} = 4.7 \times 10^{-3} H^{3/2} \tag{2}$$

From Eq. (2), letting the sound speed equal 1545 m/sec, the minimum frequency of the wave trapped in the 20 m (calculator derived) layer would be approximately 2028 Hz. The minimum frequency of the wave trapped in the 50 m (Wilson derived) layer would be nearly 514 Hz. Considering a frequency range from 50 Hz to 1700 Hz, this result is significant. The above approximations indicate no surface duct propagation in the case of the calculator derived profile. In contrast, for the Wilson's equation derived surface layer, surface duct propagation would occur at frequencies between 514 Hz and 1700 Hz.

The sound speed gradients illustrated in Figure 8 differ somewhat between 400 m and 700 m; however, the magnitude of the difference may not be large enough to produce a significant change in convergence zone propagation.

Table 8 and Figure 9 illustrate that the salinity correction significantly improved the overall calculator derived sound speed estimates. However, the layer depth estimate remains in error.

Figure 10 illustrates the temperature profile obtained from this third example data set. Significant temperature gradient changes occur at depths of 50, 75, 100, 200, 300, 400, 700 and 900 m. Using the temperatures at these depths in addition to those at the surface and the bottom would result in a sound speed profile giving no indication of the actual in situ surface layer. However, if the salinity correction is applied, the surface layer depth and sound speed at the bottom of the layer will be accurately described.

Example 4. Atlantic Ocean, Labrador Sea, 60°48.0'N, 57°0.0'W, 10/9/64

In comparison to the previous example, near-surface salinities in this Labrador Sea example, Table 9, are lower than 35 ppt. A sharp salinity discontinuity occurs between 50 m and 75 m which would be unaccounted for in the calculator program. As a result, the layer depth, Figure 11, is underestimated by 50 m. Using Eq. (2) and a sound speed of 1510 m/sec, the minimum trapped frequencies for the calculator and Wilson derived layer depths are 502 Hz and 127 Hz, respectively. In this example surface layer propagation would occur in both cases for all frequencies above the respective minima. The sound speed gradient difference noted between 50 m and 75 m (Fig. 11) might become important to transmission loss calculations if the receiver or source were located within the depth interval from 50 m to 150 m.

Table 7. Examnle 3 comparison between calculator derived and Wilson derived sound speeds.

20 28.0N 73 18.0W 9/22/63

Depth (m)	Temp. (C)	Salin. (PPT)	Salin-35 (PPT)	Wilson Sound Speed m/s	Calc Sound Speed m/s	Wilson-Calc Sound Speed m/s
0	29.45	35.45	.45	1545.4	1545.0	.4
10	29.51	35.51	.51	1545.5	1545.0	.5
20	29.42	35.56	.56	1545.6	1545.0	.6
30	29.26	35.84	.84	1545.7	1544.7	1.0
50	28.86	36.50	1.50	1545.9	1544.4	1.5
75	26.02	36.65	1.65	1540.3	1538.3	2.0
100	24.40	36.83	1.83	1537.1	1535.0	2.1
125	23.49	36.85	1.85	1535.4	1533.2	2.2
150	22.47	36.88	1.88	1533.3	1531.0	2.3
200	20.10	36.70	1.7	1527.7	1525.5	2.2
250	18.84	36.58	1.58	1524.9	1522.8	2.1
300	17.88	36.47	1.47	1522.8	1521.0	1.8
400	16.63	36.28	1.28	1520.5	1518.8	1.7
500	14.35	35.92	.92	1514.6	1513.4	1.2
600	11.88	35.54	.54	1507.6	1506.6	1.0
700	9.44	35.20	.20	1500.1	1499.6	.5
800	8.00	35.06	.06	1496.1	1496.0	.1
900	6.63	34.99	- .01	1492.4	1492.3	.1
1000	5.92	35.01	.01	1491.3	1491.4	- .1
1100	5.47	35.03	.03	1491.1	1491.1	0
1200	4.97	35.03	.03	1490.8	1490.8	0

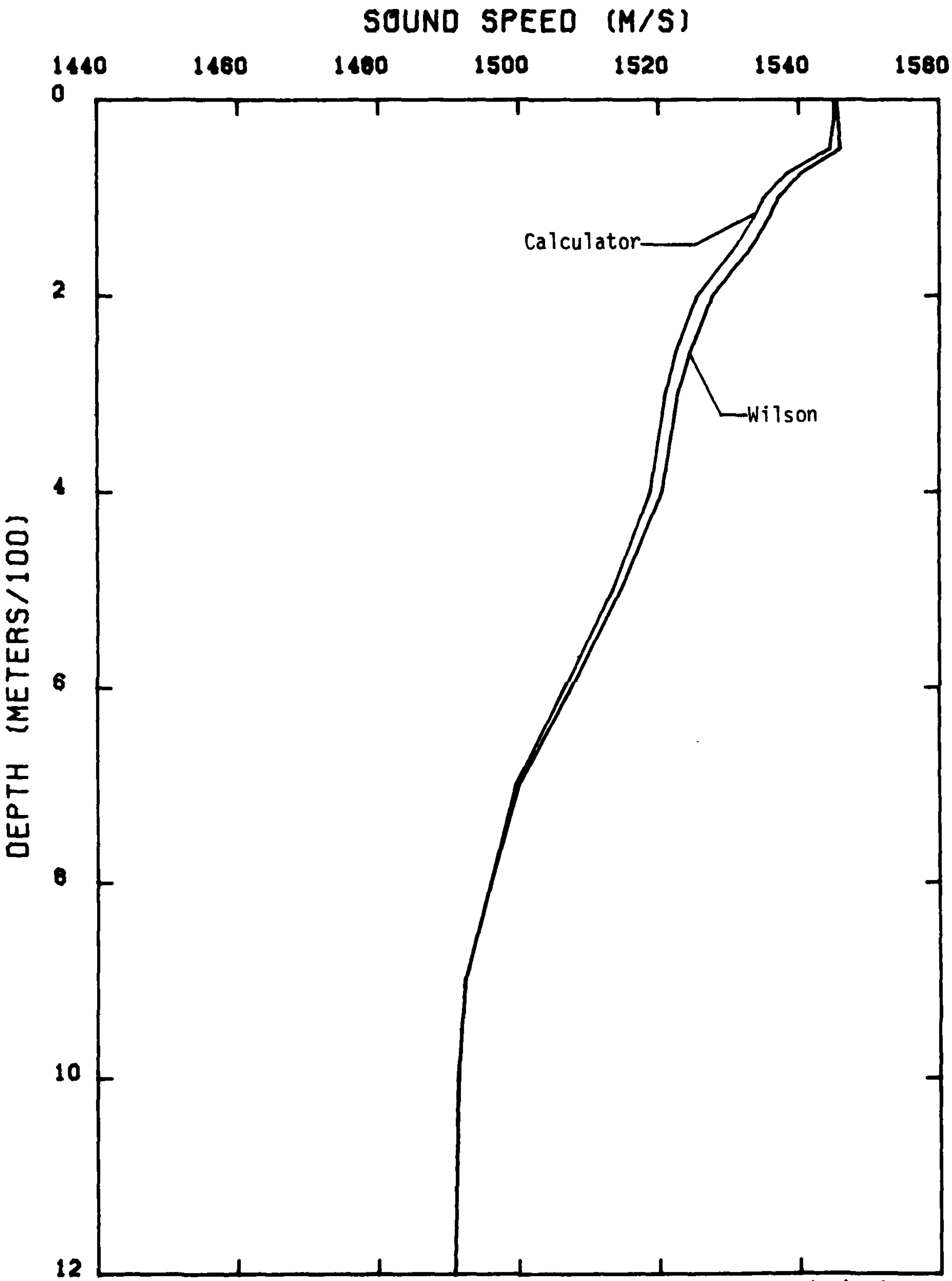

Fig. 8. Example 3 comparison between calculator and Wilson derived sound speed profiles.

Table 8. Example 3 comparison between salinity corrected calculator derived and Wilson derived sound speeds.

Depth (m)	Mean Salinity (PPT)	Sound Speed Correction @1.3 m/sec/PPT (m/s)	Calculator Corrected Sound Speed (m/s)	Wilson-Corrected Calculator Sound Speed (m/s)
0	35.68	.9	1545.9	- .5
10	35.89	.8	1545.8	- .3
20	36.07	1.4	1546.4	- .8
30	36.24	1.6	1546.3	- .6
50	36.53	2.0	1546.4	- .5
75	36.69	2.2	1540.5	- .2
100	36.83	2.4	1537.4	- .3
125	36.90	2.5	1535.7	- .3
150	36.89	2.4	1533.4	- .1
200	36.72	2.2	1527.7	0
250	36.55	2.0	1524.8	.1
300	36.43	1.8	1522.8	0
400	36.13	1.5	1520.3	.2
500	35.75	1.0	1514.4	.6
600	35.44	.6	1507.2	.4
700	35.18	.2	1499.8	.3
800	35.06	.1	1496.1	0
900	35.02	0	1492.3	.1
1000	35.02	0	1491.4	- .1
1100	35.03	0	1491.1	0
1200	35.02	0	1490.8	0

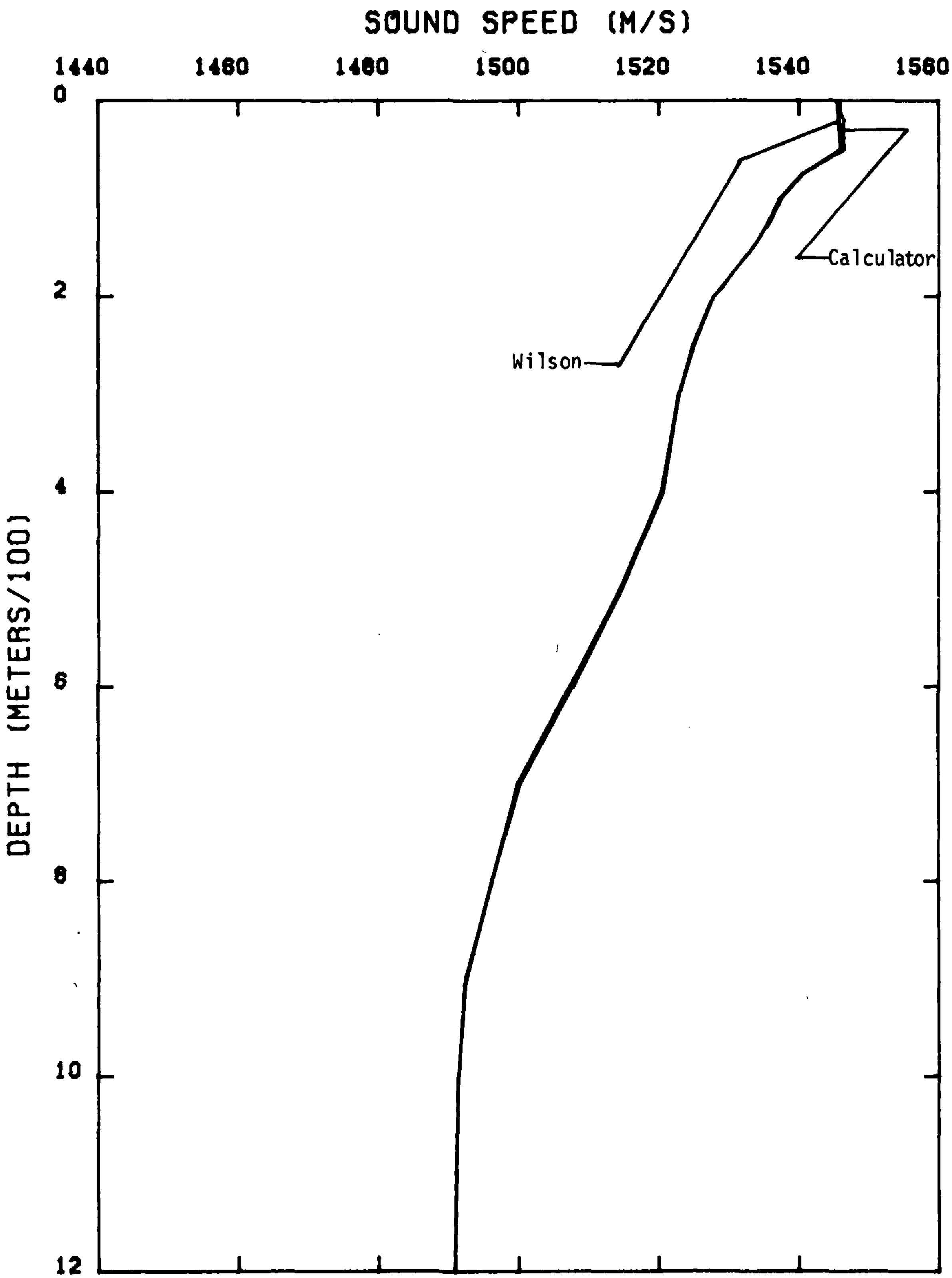

Fig. 9. Example 3 comparison between the salinity corrected calculator and Wilson derived sound speed profiles.

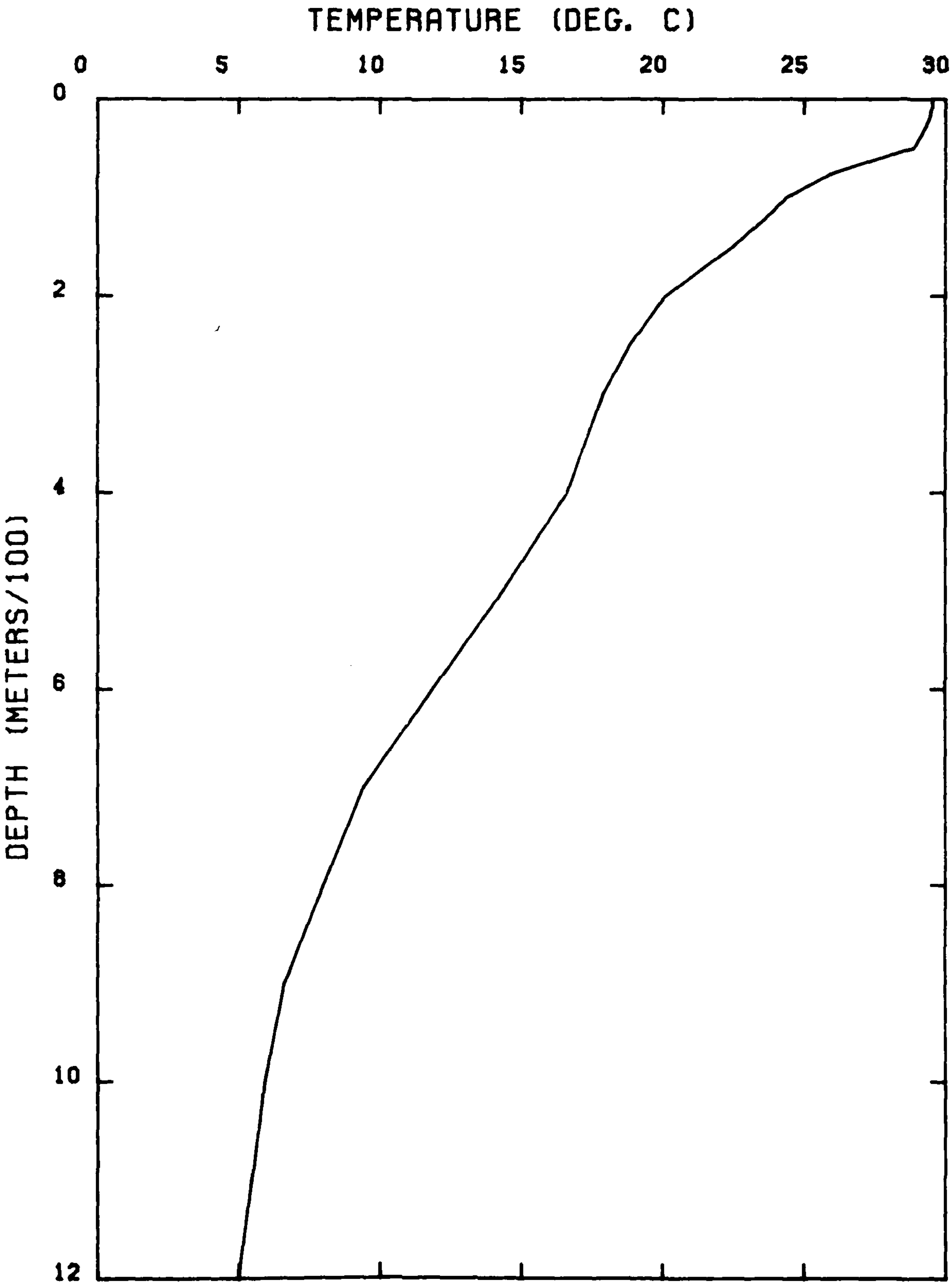

Fig. 10. Example 3 in situ temperature profile.

Table 9. Example 4. Comparison between calculator derived and Wilson derived sound speeds

62 48.0N 57 0.0W 10/9/64

Depth (m)	Temp (C)	Salinity (PPT)	Salinity-35.0 (PPT)	Wilson Sound Speed (m/s)	Calc Sound Speed (m/s)	Wilson-Calc Sound Speed (m/s)
0	5.21	34.08	- .98	1470.6	1471.9	- 1.3
10	5.21	34.09	- .91	1470.8	1472.2	- 1.4
20	5.21	34.08	- .92	1471.0	1472.2	- 1.2
30	5.21	34.08	- .92	1471.1	1472.5	- 1.4
50	5.21	34.07	- .93	1471.5	1472.8	- 1.3
75	4.88	34.80	- .20	1471.5	1471.8	- .3
100	5.46	34.94	- .06	1474.5	1474.6	- .1
125	5.30	34.94	- .06	1474.2	1474.3	- .1
150	5.18	34.93	- .07	1474.1	1474.3	- .2
200	5.05	34.95	- .05	1474.4	1474.6	- .2
250	4.94	34.94	- .06	1474.8	1474.9	+ .1
300	4.77	34.93	- .07	1474.9	1475.2	- .3
400	4.40	34.92	- .08	1475.0	1475.2	- .2
500	4.14	34.90	- .10	1475.6	1475.9	- .3
600	4.00	34.90	- .10	1476.6	1476.8	- .2

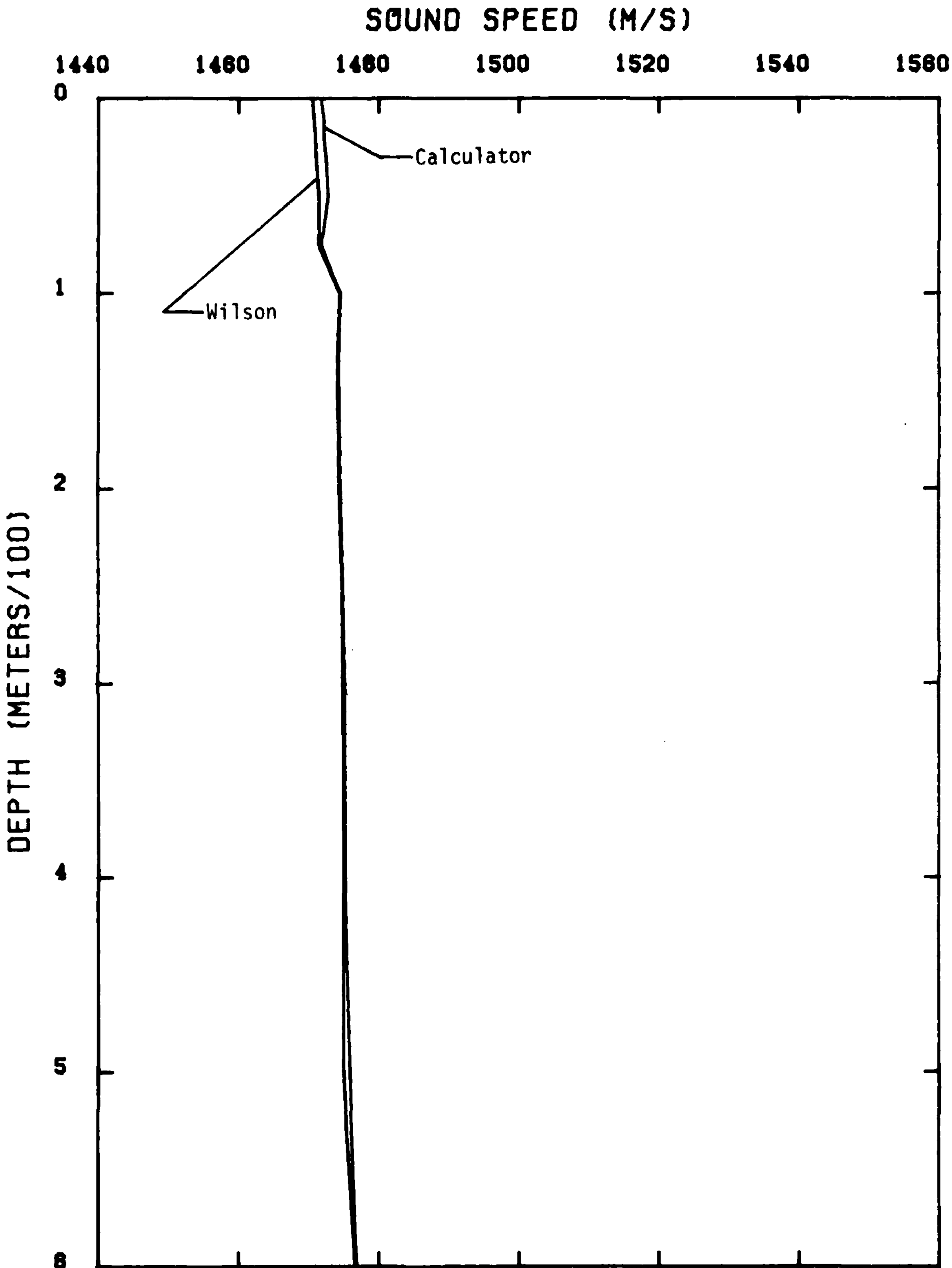

Fig. 11. Example 4 comparison between calculator and Wilson derived sound speed profiles.

Table 10 and Figure 12 illustrate the improvements to the calculator derived sound speeds that can be made using the salinity correction. Although there is a better estimate of the shape of the sound speed profile derived from Wilson's equation through the use of a salinity correction, the layer depth remains underestimated by 50 m.

Figure 13 illustrates the temperature profile obtained from the data set for this fourth example. Significant temperature gradient changes are found at depths of 100, 150, and 200 m. Using the temperatures at these depths, in addition to those at the surface and the bottom, the calculator program would provide the user with a sound speed profile in which the layer depth and the depth of the deep sound channel axis are accurately described. In this example, the temperature field contained the information necessary to accurately describe the above features. Surface, bottom of the layer, and sound channel axis sound speed magnitudes are in good agreement with those obtained from Wilson's equation (Table 9). Better estimates of the above sound speeds will be obtained if the salinity correction is applied (Table 10).

Other Sound Speed Equations

Salinity differences between the calculator program's assumed constant salinity and the in situ salinity are responsible for the major sound speed profile shape and sound speed magnitude differences identified in the examples. Because of this, some thought should be given to the use of other sound speed equations which might be less sensitive to salinity than Leroy's equation. The equations of Mackenzie (1981), Medwin (1975), Coppens (1981), and Del Grosso and Mader (1972) were examined to determine if any appeared significantly salinity insensitive. None were. The difference in salinity "sensitivity" between all the equations considered, including Leroy's, was roughly 0.06 m/sec/ppt at 0°C.

It was decided; however, to use Mackenzie's (1981) equation in the calculation of sound speeds for the four example data sets examined previously; since it was written particularly for calculator use, it is based on recent laboratory experiments (Del Grosso and Mader, 1973), and it appears slightly less sensitive to salinity than Leroy's equation. Table 11 presents differences between results obtained through the use of Mackenzie's equation, under the constant salinity assumption, and Wilson's equation in which the in situ salinity was utilized. Comparison of these and those obtained from the calculator form results in the use of Leroy's equation (Tables 3, 5, 7, and 9) reveals no significant improvement. Estimates of Wilson derived sound speed magnitudes varied from 0.7 m/sec better to 0.7 m/sec worse than those derived through the use of the calculator program. In addition, no improvements were made in the estimates of layer depths or the deep sound channel axis depth found in errors previously.

Conclusions

The calculator form of Leroy's equation differs from that originally published in that some terms were not included due to program space limitations. These missing terms were found to be inconsequential over those depths normally sampled by expendable bathythermographs. Caution must be exercised, however, in extending program utilization to depths greater than those (<2000 m) intended. At very large depths sound speed errors introduced by the omission of the Va^1 term could result in significant sound speed errors.

Table 10. Example 4 comparison between salinity corrected calculator derived and Wilson derived sound speeds.

Depth (m)	Mean Salinity (PPT)	Sound Speed Correction (m/s) @ 1.3 m/sec/PPT	Calculator Corrected Sound Speed (m/s)	Wilson-Corrected Calculator Sound Speed (m/s)
0	33.66	- 1.74	1470.1	.5
10	33.66	- 1.74	1470.5	.3
20	33.67	- 1.73	1470.5	.5
30	33.73	- 1.65	1470.8	.3
50	34.18	- 1.07	1471.7	- .2
75	34.55	- .58	1471.2	.3
100	34.72	- .36	1474.2	.3
125	34.80	- .26	1474.0	.2
150	34.86	- .18	1474.1	0
200	34.90	- .13	1474.5	- .1
250	34.93	- .09	1474.8	0
300	34.96	- .05	1475.1	- .2
400	34.95	- .06	1475.1	- .1
500	34.94	- .08	1475.8	- .8
600	34.93	- .09	1476.7	- .1

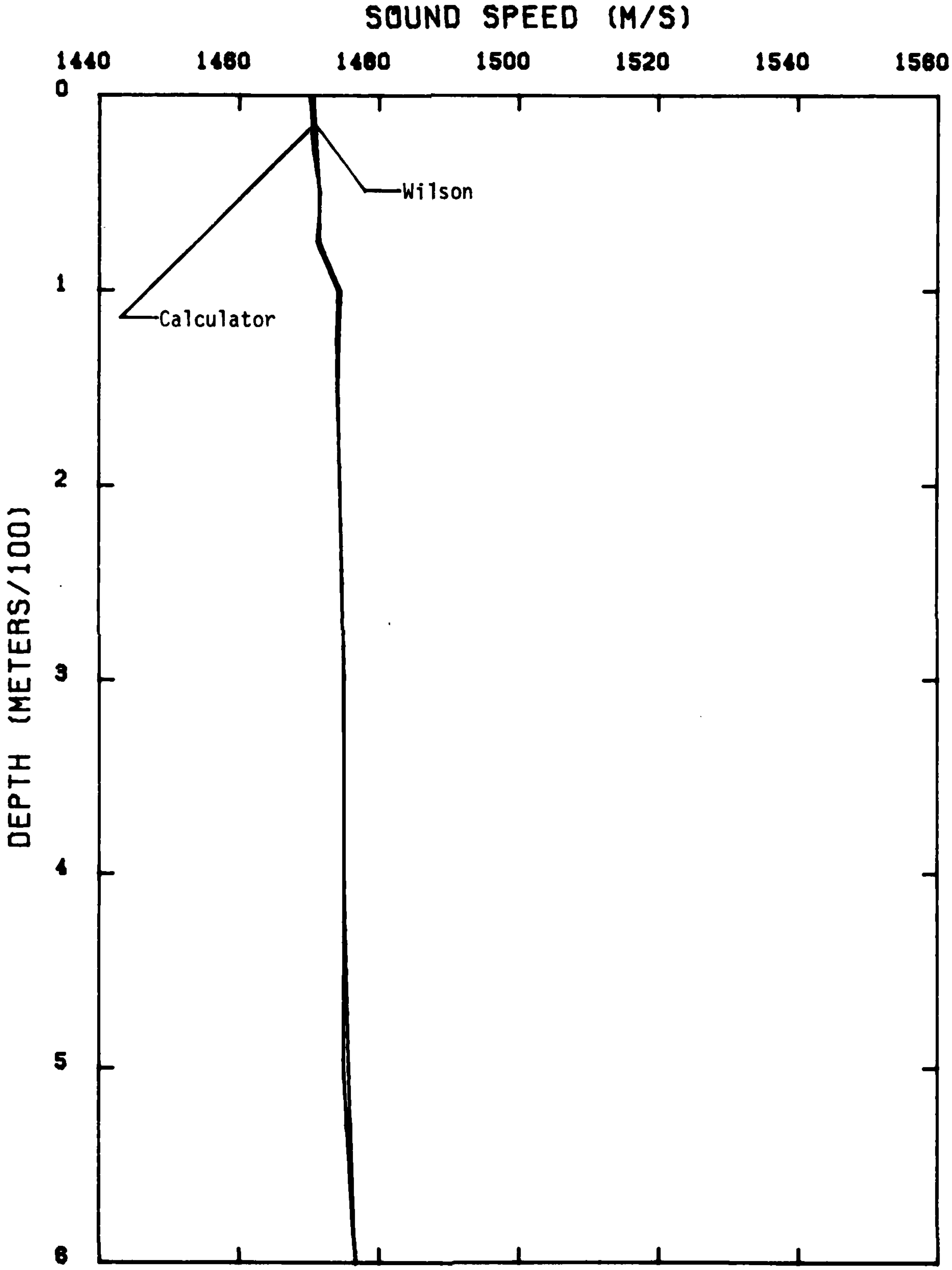

Fig. 12. Example 4 comparison between the salinity corrected calculator and Wilson derived sound speed profiles.

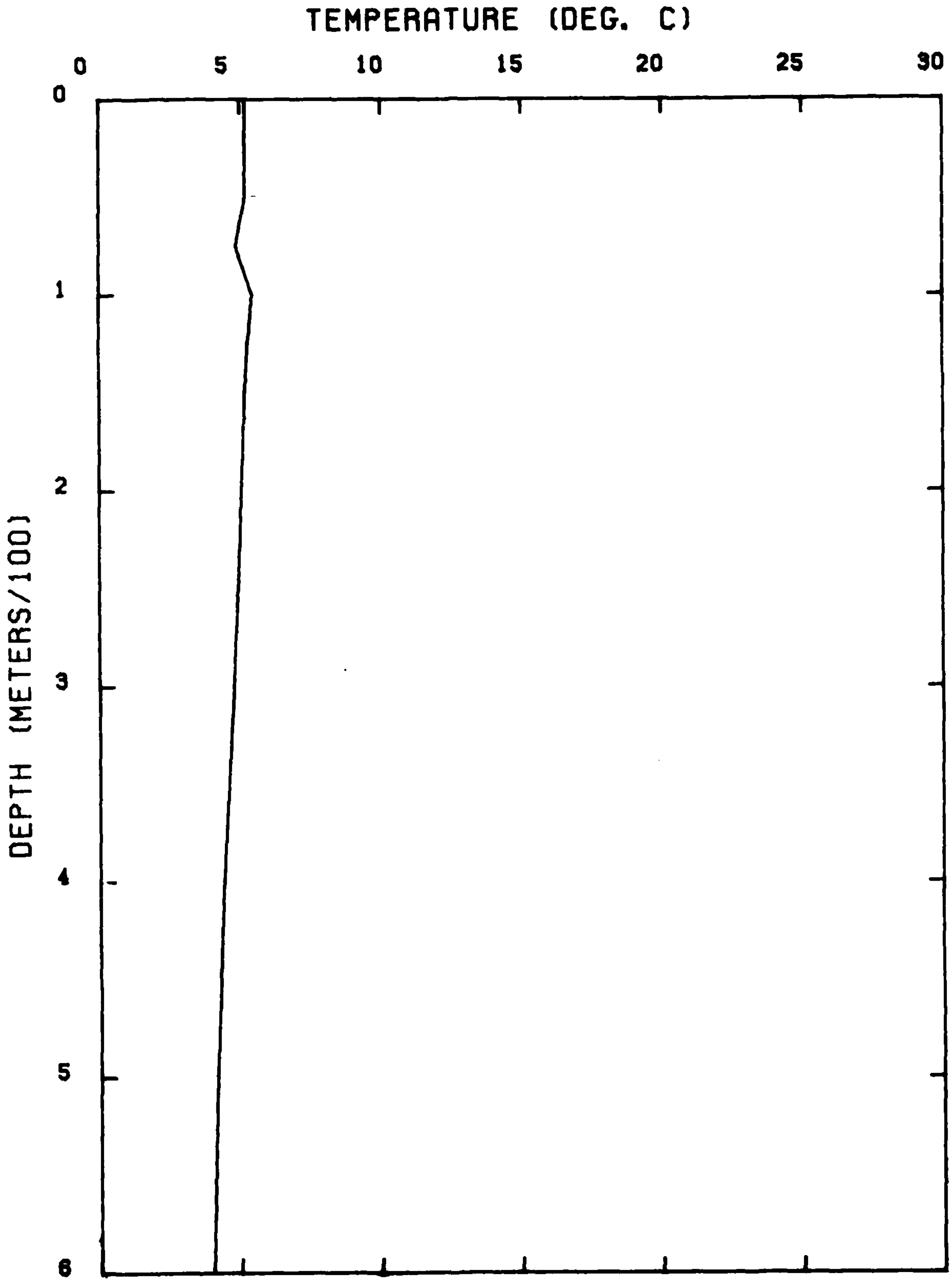

Fig. 13. Example 4 in situ temperature profile.

Table 11. Comparison between Mackenzie (1981) derived sound speeds and Wilson (1960) derived sound speeds for the four example cases. M = Mackenzie sound speed in m/sec. W = Wilson sound speed in m/sec. D = depth in meters.

	Example 1		Example 2		Example 3		Example 4	
D	M	W-M	M	W-M	M	W-M	M	W-M
0	1470.6	-2.3	1521.8	-1.9	1544.4	1.0	1471.5	-0.9
10	1470.4	-2.3	1522.0	-1.9	1544.5	1.0	1471.6	-0.8
20	1470.1	-2.3	1522.2	-1.9	1544.5	1.1	1471.8	-0.8
30	1467.9	-2.3	1518.7	-2.1	1544.3	1.4	1472.0	-0.9
50	1464.7	-2.3	1508.8	-2.3	1543.8	2.1	1472.3	-0.8
75	1460.4	-2.3	1508.7	-1.0	1537.9	2.4	1471.4	0.1
100	1460.8	-2.3	1507.7	-0.1	1534.5	2.6	1474.1	0.4
125	1461.8	-2.2	1507.2	0.2	1532.6	2.8	1473.9	0.3
200	1463.7	-2.1	1508.1	0.4	1525.0	2.7	1474.1	0.3
250	1466.6	-1.8	1508.7	0.6	1522.3	2.6	1474.4	0.4
300	1470.0	-1.5	1509,5	0.7	1520.4	2.4	1474.6	0.3
400	1472.2	-1.1	1511.0	0.7	1518.3	2.2	1474.7	0.3
500	1473.4	-0.9	1512.5	0.7	1512.8	1.8	1475.3	0.3
600	1474.4	-0.8	1514.1	0.7	1506.2	1.4	1476.3	0.3
700	1475.4	-0.6	1515.7	0.7	1499.3	0.8		
800	1476.5	-0.6			1495.6	0.5		
900	1477.5	-0.5			1491.9	0.5		
1000	1478.5	-0.4			1490.8	0.5		
1100	1479.5	-0.3			1490.6	0.5		
1200	1480.6	-0.3			1490.3	0.5		

Sound speed differences caused by the slight disagreement between the coefficients of the Vo and Vb terms of Leroy's equation and the calculator program were found to be insignificant. In addition, the program was found to reproduce consistent results (depth and sound speed) for each optional set of input units.

The most significant sound speed differences encountered in this investigation were due to the calculator program's assumption of a constant salinity. Under this assumption, sound speed magnitude differences of up to 4.7 m/sec are possible. It was shown that in regions of the ocean where large vertical salinity gradients exist, errors in the depths of the surface layer and deep sound channel axis can occur. In the extreme, it was demonstrated how an existing surface layer would not be revealed under a constant salinity assumption.

In one example case (Example 4), simulation of the BT trace and the selection of points at temperature gradient change depths did improve the estimate of the layer depth defined by the entire profile. However, by the application of a simple salinity correction based on the mean salinity at depth for each example area, it was demonstrated how overall improvements to estimates of sound speed magnitudes, layer depths, and deep sound channel axis depths could be made.

Table 12 summarizes the results of the four examples given. Bottom sound speeds and depths were estimated from historical data. The axis depth given for the third example was defined from archival data. Since this depth coincided with the maximum depth of the Nansen cast, the axis sound speeds were determined from the example data set.

Finally, although Mackenzie's equation has certain advantages, its use did not lead to any significant improvement over the use of the calculator program's version of Leroy's equation under the constant salinity assumption.

Recommendations

The following recommendations are made under the assumption that the differences in layer depths, sound channel axis depths, and sound speed magnitudes uncovered during this investigation are of significant magnitude to affect the overall system results. Most important in this regard is the sophistication of the transmission loss (TL) models into which these data are entered. The assumption is made that the data presented in Table 12 (2A versus 2B, 3A versus 3B, or 4A versus 4B for example) would give significantly different TL results.

Under the above assumption the following recommendations are made:

1.) Examine an archival salinity data base (ICAPS, for instance) to determine the most representative seasonal salinity profiles for each ocean.

2.) Determine which salinity profiles differ significantly from the most representative and define the areas for which these profiles should apply.

3.) Provide the user with a small calculator magnetic card library of the above salinity profiles from which an interpolated salinity can be derived at BT inflection point depths.

4.) Provide the user with a program to create their own salinity profile cards. In small operating areas additional accuracy should be gained by direct use of the specific (ICAPS) salinity profile generated for the area.

5.) Rewrite program V10011/B using Mackenzie's (1981) equation to calculate sound speeds using BT derived depths and temperatures and interpolated archival salinities.

Table 12. Comparison of results for the four example cases. A = calculator derived. B = Wilson equation derived. C = salinity-corrected-calculator derived. D = salinity-corrected-calculator derived from the simulated BT trace. SS = sound speed in m/sec. d = depth in meters.

	Surface	Bottom of Layer		Bottom		Axis	
Example	SS	SS	d	SS	d	SS	d
1.A	1471.3	No	Layer	1560.0	6000	1460.9	75
1.B	1468.3	No	Layer	1560.0	6000	1458.1	75
1.C	1468.7	No	Layer	1560.0	6000	1485.5	75
1.D	1468.7	No	Layer	1560.0	6000	1485.5	75
2.A	1522.5	1522.8	20	1510.6	3048	1507.9	125
2.B	1519.9	1520.3	20	1510.6	3048	1506.5	50
2.C	1519.5	1519.9	20	1510.6	3048	1507.0	50
2.D	1519.5	1519.9	20	1510.6	3048	1507.0 or 1507.0	50 125
3.A	1545.0	1545.0	20	1544.5	5000	1490.8	1200
3.B	1545.4	1545.9	50		or	1490.8	1200
3.C	1545.9	1546.4	20	1562.3	6000	1490.8	1200
3.D	1545.9	1546.4	50			1490.8	1200
4.A	1471.8	1472.8	50	1496.5	2000	1474.3	150
4.B	1470.6	1474.5	100		or	1474.1	150
4.C	1470.1	1471.7	50	1512.1	3000	1474.0	125
4.D	1470.1	1474.2	100			1474.1	150

REFERENCES

Coppens, A.B. Simple Equations for the Speed of Sound in Neptunion Waters. J. Acoust. Soc. Am. 69 (3): 862-863; 1981.

Defant, A. Physical Oceanography Vol. I. New York, N.Y. Pergamon Press Inc., 1961.

Del Grosso, V.A. Tables of the Speed of Sound in Open Ocean Water (with Mediterranean Sea and Med Sea Applicability). J. Acoust. Soc. Am. 53 (5): 1384-1401; 1973.

Del Grosso, V.A.; Mader, C.W. Speed of Sound in Sea-Water Samples. J. Acoust. Soc. Am. 53 (3) (part 2): 961-974; 1973.

Leroy, C.C. Development of Simple Equations for Accurate and More Realistic Calculation of the Speed of Sound in Seawater. J. Acoust. Soc. Am., 46 (1) (part 2): 216-226; 1968.

Mackenzie, K.V. Nine-term Equation for Sound Speed in the Oceans. J. Acoust. Soc. Am. 70 (3): 807-812; 1981.

Medwin, H. Speed of Sound in Water: A Simple Equation for Realistic Parameters. J. Acoust. Soc. Am. 58 (6) : 1318-1319; 1975.

Pickett, R. Precision of Sound Speed Estimated from Bathythermographs. U.S. Navy, NAVOCEANO, Tech. Note 7700-1-72; 1972; 5 p.

Urick, R.J. Principles of Underwater Sound. New York, N.Y. McGraw-Hill Inc., 1975.

Von Arx, W.S. An Introduction to Physical Ocenaography. Reading, Mass. Addison-Wesley Publishing Co., 1967.

Wilson, W.D. Speed of Sound in Sea Water as a Function of Temperature, Pressure, and Salinity. J. Acoust. Soc. Am. 32 (6): 641-644; 1960.

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: NORDA Technical Note 192	2. GOVT ACCESSION NO.: AD-A130 772
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): An Evaluation of Fleet Mission Program Library: Program V10011/B (Bathythermograph Sound Velocity Profile)	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): G.A. Kerr	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Ocean Research and Development Activity, NSTL Station, Mississippi 39529	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PE 63785N
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Ocean Research and Development Activity, NSTL Station, Mississippi 39529	12. REPORT DATE: January 1983
	13. NUMBER OF PAGES: 35
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

calculator program
sound velocity
bathythermograph

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Hewlett Packard 67 (or 97) calculator program used to convert a bathythermograph trace to a sound speed profile was evaluated. The program was found to use a truncated form of Leroy's equation, adequate over the shallow depths (<2000 m) considered. However, use of a constant oceanic-wide salinity value was found to give erroneous estimates of the layer depth and the depth of the deep sound channel axis in ocean areas where moderately large vertical salinity gradients are encountered. This result led to the recommendation that the

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program be rewritten to allow the use of a salinity profile representative of the area be sampled.

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